CLAIMS

Having thus described our invention in detail, what we claim as new and desire to secure by the Letters Patent is:

1. A method of producing a substantially relaxed, high-quality SiGe-on-insulator substrate material comprising the steps of:

implanting ions into a Si-containing substrate to form an implanted-ion rich region that has an ion concentration that is sufficient to act as a diffusion barrier to Ge, said implanted-ion rich region having a surface layer of the Si-containing substrate located thereon;

forming a Ge-containing layer atop the implanted Si-containing substrate; and

heating the substrate at a temperature which permits (i) formation of a diffusion barrier layer, and (ii) interdiffusion of Ge throughout said Ge-containing layer and said surface layer of Si-containing substrate located above the implanted-ion rich region thereby forming a substantially relaxed SiGe layer atop said diffusion barrier layer.

2. The method of Claim 1 wherein said implanting ions comprise oxygen ions, nitrogen ions, NO ions, inert gases or mixtures thereof.

3. The method of Claim 1 wherein said implanting ions comprise oxygen ions.

4. The method of Claim 1 wherein said implanting comprises a blanket implantation process or a masked implantation process.

5. The method of Claim 1 wherein the implanting comprises a high-dose ion implantation process that is performed using an ion dosage of about 4E17 cm^{-2} or greater.

6. The method of Claim 5 wherein the high-dose ion implantation is carried out in an ion implantation apparatus that operates at a beam current density of from about 0.05 to about 500 milliamps cm^{-2} and at an energy of from about 150 to about 1000 keV.

7. The method of Claim 5 wherein the high-dose ion implantation process is carried out at a temperature of from about 200°C to about 800°C.

8. The method of Claim 5 wherein said high-dose ion implantation process comprises a base ion implantation step followed by a second ion implantation step that is carried out a temperature of from about 4K to about 200°C.

9. The method of Claim 8 wherein the second ion implantation step is carried out using an ion dose of about 1E14 to about 1E16 cm^{-2}, an energy of from about 40 keV or greater, with a beam current density of from about 0.05 to about 10 mA cm^{-2}.

10. The method of Claim 1 wherein the implanting comprises a low-dose ion implantation process that is performed using an ion dosage of about 4E17 cm^{-2} or less.

11. The method of Claim 10 wherein the low-dose ion implantation is carried out in an ion implantation apparatus that operates at a beam current density of from about 0.05 to about 500 milliamps cm^{-2} and at an energy of from about 40 to about 10000 keV.

12. The method of Claim 10 wherein the low-dose ion implantation process is carried out at a temperature of from about 100°C to about 800°C.

13. The method of Claim 10 wherein said low-dose ion implantation process comprises a base ion implantation step followed by a second ion implantation step that is carried out a temperature of from about 4K to about 200°C.

14. The method of Claim 13 wherein the second ion implantation step is carried out using an ion dose of about 1E14 to about 1E16 cm^{-2}, an energy of from about 40 keV or greater, with a beam current density of from about 0.05 to about 10 mA cm^{-2}.

15. The method of Claim 1 wherein the Ge-containing layer is a SiGe alloy layer or pure Ge.

16. The method of Claim 1 wherein the Ge-containing layer is a SiGe alloy layer comprising up to 99.99 atomic percent Ge.

17. The method of Claim 1 wherein said Ge-containing layer is formed by an epitaxial growth process selected from the group consisting of low-pressure chemical vapor deposition, atmospheric pressure chemical vapor deposition, ultra-high vacuum chemical vapor deposition, molecular beam epitaxy, and plasma-enhanced chemical vapor deposition.

18. The method of Claim 1 further comprising forming a Si cap layer atop said Ge-containing layer prior to said heating.

19. The method of Claim 18 wherein said Si cap layer comprises epi-Si, epi-SiGe, a:Si, a:SiGe, single or polycrystalline Si or any combination and multilayer thereof.

20. The method of Claim 1 wherein a surface oxide layer forms during said heating.

21. The method of Claim 20 further comprising removing said surface oxide layer utilizing a wet chemical etch process.

22. The method of Claim 1 wherein said heating is carried out in an oxidizing ambient which comprises at least one oxygen-containing gas.

23. The method of Claim 22 further comprising an inert gas, said inert gas being employed to dilute said at least one oxygen-containing gas.

24. The method of Claim 1 wherein said heating is performed at a temperature of from about 900°C to about 1350°C.

25. The method of Claim 1 further comprising growing an additional SiGe layer atop said substantially relaxed SiGe layer.

26. The method of Claim 25 further comprising forming a strained Si layer atop said additional SiGe layer.

27. The method of Claim 1 further comprising forming a strained Si layer atop said substantially relaxed SiGe layer.

28. A substrate material comprising:

a Si-containing substrate;

an insulating region that is resistant to Ge diffusion present atop said Si-containing substrate; and

a substantially relaxed SiGe layer present atop said insulating region, wherein said substantially relaxed SiGe layer has a thickness of about 2000 nm or less and a defect density of from about 5×10^7 atoms/cm^{-2} or less.

29. The substrate material of Claim 28 wherein said insulating region is patterned or unpatterned.

30. The substrate material of Claim 28 wherein said insulating region is a buried oxide region.

31. The substrate material of Claim 28 wherein said substantially relaxed SiGe layer has a measured lattice relaxation of from about 1 to about 100 %.

32. A heterostructure comprising:

a Si-containing substrate;

an insulating region that is resistant to Ge diffusion present atop the Si-containing substrate;

a substantially relaxed SiGe layer present atop the insulating region, wherein the substantially relaxed SiGe layer has a thickness of about 2000 nm or less and a defect density of from about 5×10^7 atoms/cm^{-2} or less; and a strained Si layer formed atop the substantially relaxed SiGe layer.

33. The heterostructure of Claim 32 wherein said insulating region is patterned or unpatterned.

34. The heterostructure of Claim 32 wherein said insulating region barrier layer is a buried oxide region.

35. The heterostructure of Claim 32 wherein said substantially relaxed SiGe layer has a measured lattice relaxation of from about 1 to about 100 %.

36. The heterostructure of Claim 32 wherein said strained Si layer comprises an epi-Si layer.

37. The heterostructure of Claim 32 wherein alternating layers of relaxed SiGe and strained Si are formed atop said strained Si layer.

38. The heterostructure of Claim 32 wherein said strained Si layer is replaced with a lattice mismatched compound selected from the group consisting of GaAs and GaP.

39. A method of producing a substantially relaxed, high-quality SiGe-on-insulator substrate material comprising the steps of:

subjecting a Si-containing substrate to a base oxygen ion implant step to form a damaged region that has an oxygen ion concentration that is sufficient to act as a diffusion barrier to Ge;

subjecting the Si-containing substrate having said damaged region to a second oxygen implant step to form an amorphous region that is shallower than the damaged region, said amorphous region having a surface layer of the Si-containing substrate thereon;

forming a Ge-containing layer atop the surface layer of the Si-containing substrate, said Ge-containing layer having a thickness from about 50 to about 500 nm and a Ge content from about 5 to about 40 atomic %;

heating the substrate to form a substantially relaxed SiGe layer atop said diffusion barrier layer, said heating comprises:

(i) first ramping up the substrate in an oxygen-containing gas to a first temperature that is sufficient to initiate formation of a buried oxide region in said substrate, while substantially avoiding slip generation;

(ii) first soaking at the first temperature to form a continuous buried oxide in said substrate;

(iii) second ramping up in an oxygen-containing gas from the first temperature to a second temperature that is sufficient to increase the thickness of the buried oxide in said substrate;

(iv) second soaking in an oxygen-containing gas at said second temperature to increase and control the thermal oxide thickness and to provide a sharpened interface between the relaxed SiGe layer and the buried oxide;

(v) ramping down from the second temperature to a third temperature that is less than or equal to the melting point of a final desired Ge concentration, while allowing Ge diffusion for concentration homogenization; and

(vi) oxidizing at said third temperature to provide the relaxed SiGe layer having said final Ge content and a thickness that is sufficient to minimize stacking faults.

40. The method of Claim 39 wherein said base oxygen implant step is performed at an energy from about 100 to about 220 keV and at a dose from about 1.5E17 to about 3E17 cm^{-2}.

41. The method of Claim 40 wherein the base oxygen implant step is performed at an energy from about 150 to about 175 keV and at a dose from about 1.8E17 to about 2.75E17 cm^{-2}.

42. The method of Claim 39 wherein said base oxygen implant is performed at a temperature from about 200°C to about 600°C at a beam current density from about 0.01 to about 0.1 milliamps cm^{-2}.

43. The method of Claim 39 wherein the second oxygen implant is performed at an energy from about 100 to about 220 keV and at a dose from about 1E15 to about 3E15 cm^{-2}.

44. The method of Claim 43 wherein the second oxygen implant is performed at an energy from about 150 to about 170 keV and at a dose from about 2E15 to about 2.75E15 cm^{-2}.

45. The method of Claim 39 wherein the second oxygen implant is performed at an implant temperature from about -200°C to about 150°C and at a beam current density from about 0.001 to about 0.01 mA cm^{-2}.

46. The method of Claim 39 wherein the Ge-containing layer is formed by an epitaxial growth process selected from the group consisting of low-pressure chemical vapor deposition, atmospheric pressure chemical vapor deposition, ultra-high vacuum chemical vapor deposition, molecular beam epitaxy, and plasma-enhanced chemical vapor deposition.

47. The method of Claim 39 wherein the Ge source used during said epitaxial growth process is isotopically enriched in any naturally occurring masses.

48. The method of Claim 39 wherein said Ge-containing layer has a thickness from about 100 to about 200 nm and a Ge content from about 15 to about 25 atomic % .

49. The method of Claim 39 further comprising forming a Si-containing cap layer atop said Ge-containing layer prior to said heating.

50. The method of Claim 49 wherein said Si-containing cap layer comprises epi-Si, epi-SiGe, a:Si, a:SiGe, single or polycrystalline Si or any combination and multilayer thereof.

51. The method of Claim 39 wherein a Si-containing buffer layer is formed atop said Si-containing substrate prior to the formation of said Ge-containing layer.

52. The method of Claim 39 wherein a surface oxide layer forms during said heating.

53. The method of Claim 52 further comprising removing said surface oxide layer utilizing a wet chemical or reactive-ion etch process.

54. The method of Claim 39 further comprising a step of subjecting the relaxed SiGe layer to a non-selective thinning process after said heating.

55. The method of Claim 54 wherein the non-selective thinning process comprises chemical mechanical polishing, grinding, high-pressure oxidation, wet etching, steam oxidation, gas-cluster beam thinning or any combination thereof.

56. The method of Claim 55 wherein the non-selective thinning process is chemical mechanical polishing.

57. The method of Claim 39 wherein the first temperature of said first ramp up is from about 1275°C to about 1320°C.

58. The method of Claim 39 wherein the first ramp up is performed using a rate of less than or equal to 1°C/min.

59. The method of Claim 39 wherein the oxygen-containing gas may further be diluted with an inert gas.

60. The method of Claim 39 wherein said first soak is performed for a period of time from about 0.5 to about 5 hours using the same or substantially the same oxygen-containing gas as the first ramp up.

61. The method of Claim 39 wherein the second temperature of the second ramp up is from about 1315°C to about 1335°C.

62. The method of Claim 61 wherein said second ramp up is performed at a rate of less than or equal to 1°C/min.

63. The method of Claim 39 wherein the second ramp up is performed in an oxygen-containing gas that is admixed with an inert gas.

64. The method of Claim 39 wherein the second soaking is performed for a time period from about 1 to about 10 hours in the same or substantially the same ambient as used in the second ramp up.

65. The method of Claim 39 wherein the third temperature of said ramping down is from about 1300°C to about 1200°C.

66. The method of Claim 39 wherein said ramp down is performed at a rate of less than or equal to 1°C/min.

67. The method of Claim 39 wherein said oxidizing is performed in 100% oxygen, steam or an oxygen-containing gas that is diluted with an inert gas.

68. The method of Claim 39 wherein the oxidizing is performed for a time period from about 1 to about 10 hours.

69. The method of Claim 39 further comprising growing an additional SiGe layer atop said substantially relaxed SiGe layer.

70. The method of Claim 69 further comprising forming a strained Si-containing layer atop said additional SiGe layer.

71. The method of Claim 39 further comprising forming a strained Si-containing layer atop said substantially relaxed SiGe layer.

72. A substrate material comprising:

a Si-containing substrate;

a buried oxide that is resistant to Ge diffusion present atop said Si-containing substrate; and

a substantially relaxed SiGe layer present atop said buried oxide, wherein said substantially relaxed SiGe layer has a surface roughness of about 1.5 nm or less, and a crystal defect density of about 5×10^7 /cm^2 or less.

73. The substrate material of Claim 72 further comprising a first strained Si-containing layer located atop the substantially relaxed SiGe layer.

74. The substrate material of Claim 73 further comprising alternating layers of relaxed SiGe and strained Si located atop the first strained Si-containing layer.

75. The substrate material of Claim 72 further comprising a layer composed of at least III-V elements located atop the substantially relaxed SiGe layer.

76. The substrate material of Claim 72 wherein said buried oxide has a mini-breakdown field of about 6MV/cm or greater.